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DTC TECHNIQUE FOR DFIG WITHOUT CROWBAR PROTECTION UNDER VOLTAGE DIPS

Masarath Unnisa[1], Amir Bin Ahmed Bashar[2], Ghouse-Ul-Islam[3], S.Humera Sadia[4], Fahmida Iqbal[5], Mohd. Abdul Kareem[6], Mohammed Abdul Rahman Uzair[7]

[1,2,3,4,5,6,7] EEE,Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad, (India)

ABSTRACT

This paper focuses on the analysis of the control over Doubly Fed Induction Generator (DFIG) based high-power wind turbines when they operate under presence of voltage dips. The main objective of the control strategy proposed for doubly fed induction generator based wind turbines is to eliminate the necessity of the crowbar protection when low-depth voltage dips occurs. A direct torque control strategy that provides fast dynamic response accompanies the overall control of the wind turbine. The proposed control does not totally eliminate the necessity of the typical crowbar protection for turbines it eliminates the activation of this protection during low depth voltage dips. Due to voltage dips in the wind turbine, three main problems occur, namely control difficulties, disturbance in the stator flux, increase of voltage and currents in the rotor of the machine. The DC bus voltage available in the back-to-back converter determines the intensity of voltage dips that can be kept under control. The modelling of the complete system is done in MATLAB-SIMULINK. Simulation results show the proposed control strategy that mitigates the necessity of the crowbar protection during low depth voltage dips.

Keywords: Crowbar Protection, Doubly Fed Induction Generator (DFIG), Direct Torque Control (DTC), perturbations, voltage dips.

I. INTRODUCTION

Wind power penetration levels have increased in electricity supply systems in few countries in recent years, so have concerns about how to incorporate this significant amount of intermittent, uncontrolled and non-dispatchable generation without disrupting the finely-tuned balance that network systems demand. GRID-connected wind electricity generation is showing the highest rate of growth of any form of electricity generation, achieving global annual growth rates in the order of 20-25%. The proposed paper presents a control strategy of generating a rotor flux wind turbine considerably reducing the stator and rotor over currents during faults. It is specially designed to address perturbations such as voltage dips, keeping them controlled. The torque of the control does not totally eliminate the necessity of the typical crowbar protection for this kind of turbines, it eliminates the activation of this protection during low depth voltage dips.

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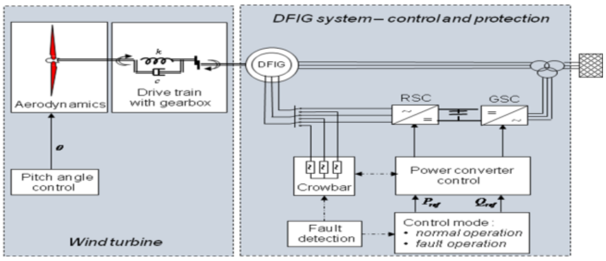

Figure 1: DFIG system control and protection

The simulated wind turbine is of 2MW, 690V, Ns/Nr =1/3 and two pair of poles of DFIG. The main objective of this simulation is to show the DFIG behavior when a low depth symmetric voltage dip occurs with and without the proposed flux reference generation strategy and at nearly constant speed.

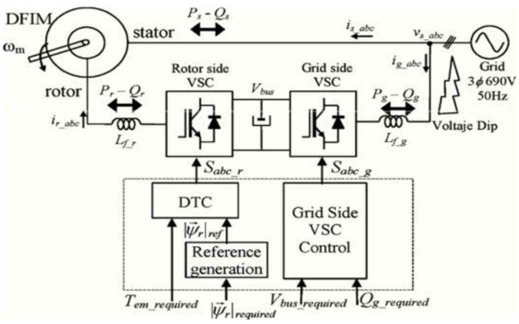

Figure 2: Schematic diagram

II. DIRECT TORQUE CONTROL

The Direct Torque Control (DTC) method is basically a performance enhanced scalar control method. The main features of DTC are direct control of flux and torque by the selection of optimum inverter switching vector, indirect control of stator at standstill. The advantages of DTC are minimal torque response time, absence of coordinate current and voltages, approximately sinusoidal stator flux and stator currents and high dynamic performance even transformations which are required in most of vector controlled drive implementation and absence of separate voltage modulation block which is required in vector controlled drives. The disadvantages of DTC are inherent torque and stator flux ripple and requirement for flux and torque estimators implying the consequent parameters identification. The complete block diagram of DTC is shown in Figure 3.

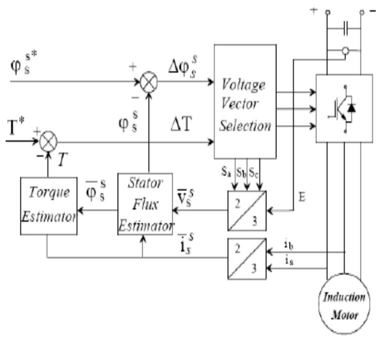

Figure 3: Direct torque control

There are two hysteresis control loops, one for the control of torque and the other for the control of flux. The flux controller controls the machine operating flux to maintain the magnitude of the operating flux at the rated value till the rated speed and at a value decided by the field weakening block for speeds above the rated speeds. Torque control loop maintains the torque value to the torque demand. The output of these controllers together with the instantaneous position of flux vector selects a proper voltage vector. So it is very important to estimate the stator flux and motor torque accurately.

III. PROBLEM STATEMENTS

Grid integration issues are a challenge to the expansion of wind power in some countries. Measures such as aggregation of wind turbines, load and wind forecasting and simulation studies are expected to facilitate larger grid penetration of wind power. In this paper simulation studies on grid connected wind electric generators (WEG) employing

i) Squirrel Cage Induction Generator (SCIG) and
ii) Doubly Fed Induction Generator (DFIG) has been carried separately. Their dynamic responses to disturbances such as variations in wind speed, occurrence of fault etc., have been studied, separately for each type of WEG.

IV. POWER FROM WIND

The power that can be captured from the wind with a wind energy converter with effective area A_r is given by:

$$P=1/2\rho_{air}C_P A V_w^3 \quad \text{…….. (1)}$$

Where $\mathbf{p}_{air}$ is the air mass density [kg/m3], V_w is the wind speed and *Cp* is the so-called power coefficient which depends on the specific design of the wind converter and its orientation to the wind direction. Its theoretical maximum value is 16/27 = 0.593 (Betz limit).

For a wind turbine with given blades it can be shown that the power coefficient *Cp* basically depends only on the tip speed ratio *l*, which equals the ratio of tip speed *vt* [m/s] over wind speed *vw* [m/s] and the so-called blade pitch angle *q* [deg]. This pitch angle is defined as the angle between the cord of the blade and the plane of the wind rotor. So, for a wind rotor with radius *r*, it can be rewritten as:

$$P=1/2\rho_{air}C_P(\lambda,\theta)\pi r^2 V_w^3 \quad \text{…………..(2)}$$

As an example, Figure 4 shows the dependency of the power coefficient *Cp* on the tip speed ratio *l* and the blade pitch angle *q* for a specific blade. For this blade maximum energy capture from the wind is obtained for *q* =0 and *l* just above 6. To keep *Cp* at its optimal value for varying wind speed, the rotor speed should be proportional to the wind speed. In practice, both constant *l* (variable speed) and constant speed operation is applied.

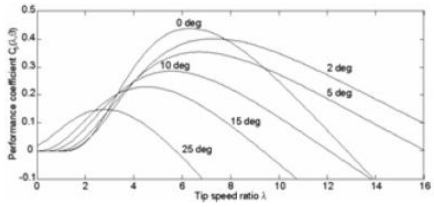

Figure 4: Power wind characteristics

For on shore turbines, the blades are designed such that the optimal tip speed is limited to roughly 70 m/s. This is attainable since the blade tips cause excessive acoustical noise at higher tip speeds. For offshore turbines, the noise does not play an important role and higher speeds are used, leading to slightly higher optimal values of *Cp*.

The relation between wind speed and generated power is given by the power curve as depicted in Figure 5. The power curve can be calculated from (2) where the appropriate value of *l* and *q* should be applied.

In the power curve, four operating regions can be distinguished that apply both to constant speed and variable speed turbines:

1. No power generation due to the low energy content of the wind.
2. Less than rated power generation. In this region, optimal aerodynamic efficiency and energy capture is aimed at. The wind speed at the boundary of region 2 and 3 is called the rated wind speed and all variables with the subscript rated refer to design values at this wind speed.
3. Generation of rated power, because the energy content of the wind is enough. In this region, the aerodynamic efficiency must be reduced because otherwise the electrical system would become overloaded.
4. No power generation because of high wind speeds the turbine is closed down to prevent damage.

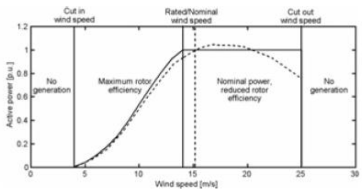

Figure 5: Typical power curve of a constant speed stall (dotted) and a variable speed pitch (solid) controlled wind turbine

V. ENERGY YIELD

The annual energy yield *E* of a wind turbine depends on its power curve *P(vw)* and the probability density distribution function *u(vw)* of the wind speed at the turbine site:

$$E=\int P(v_w).u(v_w)dv_w \qquad \ldots\ldots\ldots(3)$$

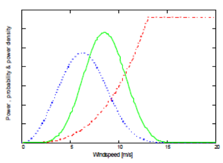

Figure 6: energy yield characteristics

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Power P (red, dashed), probability density U (blue, dotted) and power density (green, solid) as a function of wind speed (arbitrary units).

VI. CURRENTLY USED GENERATOR SYSTEMS

The three most commonly used generator systems applied in wind turbines are depicted in Figure 7.

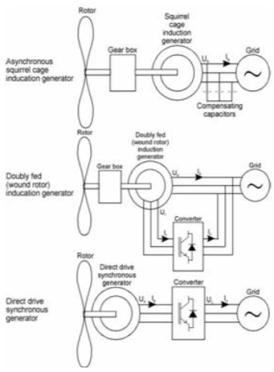

Figure 7: The three commonly used generator systems

1) Constant speed wind turbine with squirrel cage induction generator (CT)

Between the rotor and the generator, there is a gearbox so that a standard (mostly 1500rpm) squirrel cage induction generator can be used. The generator is directly connected to the 50Hz or 60Hz utility grid.

There are a few variants:

1. pole changing generators with two stator windings with different numbers of pole pairs so that the turbine can operate at two constant speeds in order to increase energy yield and reduce audible noise and

2. Generators with electronically variable rotor resistance in order to reduce mechanical loads by making larger speed variations possible: the semi variable speed wind turbine.

2) Variable speed wind turbine with doubly-fed (wound rotor) Induction generator (VTDI).

Between the rotor and the generator, there is a gearbox so that a standard (mostly 1500 rpm) doubly-fed induction generator can be used. The stator is directly connected to the utility grid. The rotor is connected to a converter. A speed range from roughly 60% to 110 % of the rated speed is sufficient for a good energy yield, that is achieved by using the variable speed capability to keep the tip speed ratio l at the value resulting in optimal energy capture. If the gearbox ratio is chosen such that the synchronous speed of the generator just falls in the middle of the speed range (in this case at 85% of rated speed), then the lowest converter power rating is Obtained. A converter rating of roughly 35 % of the rated turbine power is sufficient, particularly when star-delta switching at the rotor winding is applied. At wind speeds above the rated wind speed, the power is reduced by pitching the blades.

3) Variable speed wind turbines with direct-drive synchronous generator (VTDD)

In this system, no gearbox is necessary because the generator rotates at very low speed, typically 10 to 25 rpm for turbines in the MW range Standard generators can therefore not be used and generators have to be developed specifically for this application. These generators are very large because they have to produce a huge torque. The total turbine power goes through a converter that converts the varying generator frequency to the constant grid frequency. At wind speeds above the rated wind speed, the power is again reduced by pitching the blades.

6.1. Comparison of the three systems

Table-1 gives an overview of the characteristics of the three different systems. The criteria for comparison are discussed below:

Table I: Comparisons of the three wind turbine concepts,+strength,-weakness

Description		CS	VTDI	VTDD
Cost,size and Weight		+	+/-	-
Suitability for 50 and 60 Hz grid frequency		-	-	+
Audible noise from blades		-	+	+
Energy yeild	Variable speed	-	+	+
	Gearbox	-	-	+
	Generator	+	+	-
	Converter	+	+/-	-
Reliability and Maintenance	Brushes	+	-	- (PM:+)
	Gearbox	-	-	+
	Mechanical loads	-	+	+
	Complexcity	+	-	-
Power quality	'flicker'	-	+	+
	Grid V&f control possible	-	+	+
	Harmonics	+	-	-
Grid faults	Fault currents	+	+	+/-
	Restoring Voltage	-	+	+

VII. POWER FROM WIND

The relationship between the powers produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below:

$$P_{wind}=\pi/8dD^2V_{wind}{}^3 \quad \text{.................} (4)$$

Wind power has the following advantages over the traditional power plants.

- Improving price competitiveness
- Modular installation
- Rapid construction
- Complementary generation
- Improved system reliability and
- Non-polluting.

VIII. RESULTS

The resulting waveforms are shown in Figures- 8 to 14.

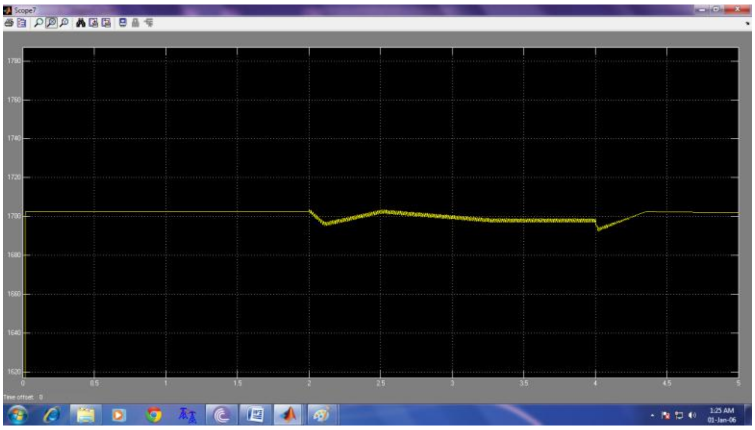

Figure 8: Speed of DFIG

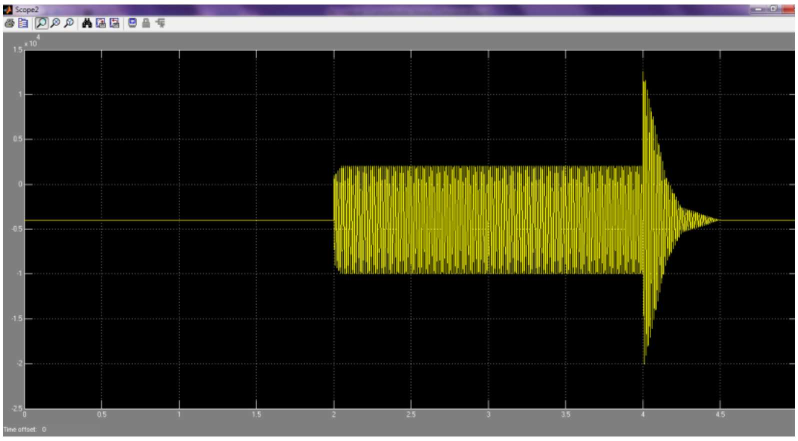

Figure9: Torque for DFIG

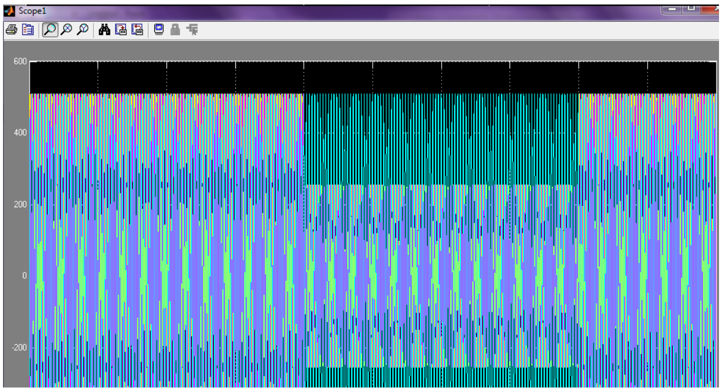

Figure 10: Input converter voltage

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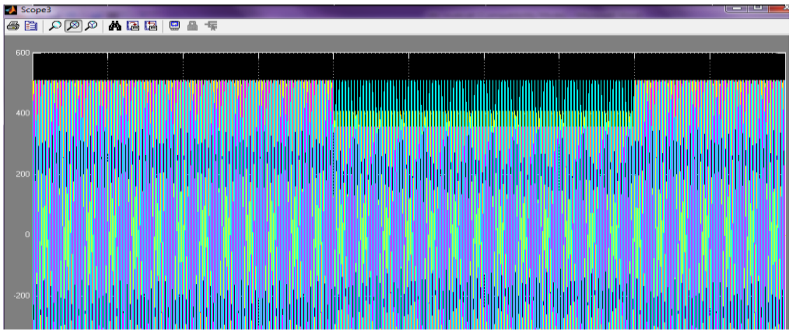

Figure 11: Inverter V_{abc} voltage with voltage dips

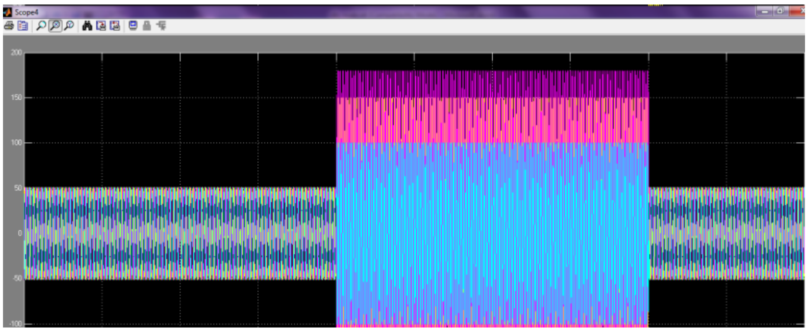

Figure 12: Recovered voltage dips in V_{abc}

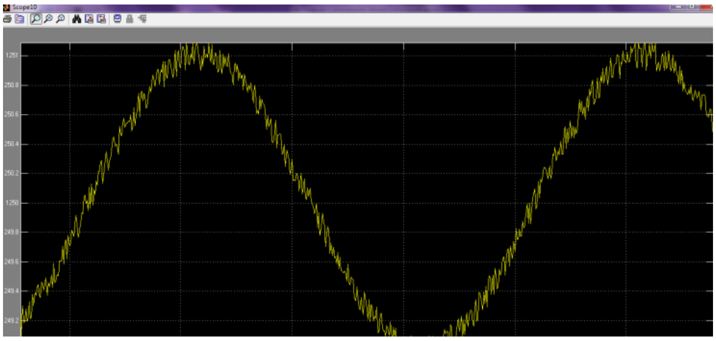

Fig . 13: Line voltage of inverter output

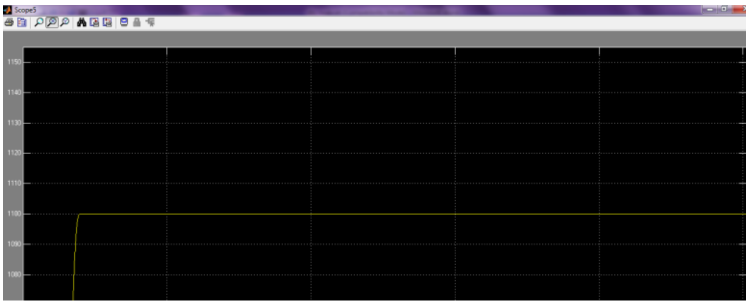

Figure 14: V_{dc} at converter output voltage

IX. CONCLUSION

The Direct Torque Control of Doubly Fed Induction Machine is used to generate the required rotor pulses using the rotor flux reference generation strategy. The proposed control strategy is used during the low depth voltage dips. For higher voltage dips, it is necessary to use crowbar protection. The DC bus voltage available in the

Back-To-Back converter determines the voltage dips depth that can be kept under control. The direct torque control combines the benefits of vector control and direct self-control into a sensor-less variable-frequency drive that does not require a PWM modulator. Under steady state, there is a ripple in the torque. This ripple depends on the switching frequency of the inverter which is determined by the torque and flux band. At the time of starting DTC draws high current. The switching frequency of the inverter varies over a wide range because of using hysteresis controllers. The magnitude of the stator flux can be maintained constant and several bright spots show the points where stator flux halts. Under transient state, the highest torque response can be obtained by selecting the fastest accelerating voltage vector to produce the maximum slip frequency. Under steady state, by selecting the acceleration vector and the zero voltage vectors alternatively, the torque can be maintained constant. Since the flux ripples are relatively small and minor loops are not observed in the locus, harmonic losses and acoustic noise of the machine may be effectively decreased. The transient response of the drive is fast with independent control of flux and the torque. Thus, the DTC offers excellent dynamic performance and gives good torque response than the field oriented control. It may be predicted that the DTC will be the most preferred control algorithm for AC drives in future because of its simplicity in control logic.

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